

## A Review of Implant Design, Geometry and Placement

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Neil Meredith

University of Bristol, UK

### INTRODUCTION

Bone is a unique structural material. Its physical and mechanical properties mimic both natural materials such as wood and man-made materials including polymers. Its mechanical properties can be directly correlated to its complex structure and it should therefore be described as an anisotropic material (Carter & Beaupre, 2001). In contrast many man-made polymers have a uniform structure in all directions and can thus be considered homogenous materials. Bone's unique property is its ability to form new bone and to remodel existing bone. This is especially important in its response to applied mechanical stresses (Carter et al, 1998).

#### *Bone healing considerations*

In the complete absence of stress bone can and will form and remodel; as with the bone formation occurring during osseointegration in the submerged phase of a two-stage implant (Lekholm & Zarb, 1985). There is also evidence to show that the application of light mechanical loads can induce favourable stresses within the bone, which may induce accelerated and enhanced bone formation (Pilliar & Maniopoulos, 1986). Much research has been carried out to analyse the influence of mechanical stress on bone formation, but it is extremely difficult to model these parameters in a laboratory or even an animal model (Brunski, 1999, Brunski et al, 1993).

It is clear that the application to bone of mechanical stresses in excess of a certain threshold level will not induce bone formation but can lead to the formation of a fibrous tissue capsule and malunion, or in the case of dental implants a failure of osseointegration (Szmukler-Moncler et al. 1998). This threshold is not clearly known or defined and is likely to vary in individual cases and sites in relation to bone quality and quantity, the loading conditions applied, and the systemic and regenerative capacities of the patient (Brunski et al, 2001). There is clearly a need to optimise the factors associated with implant placement and design which can optimise the conditions for bone remodelling or formation under immediate and early loading conditions (Sennerby & Roos, 1998)

#### *Biomechanics of implant placement and loading*

There are three main biomechanical parameters that influence the stress distribution and optimal stability of an implant in bone; these are the placement procedures including the drilling of the osteotomy site and the use of compression techniques to increase local stability (O'Sullivan et al. 2004a). Secondly, the design features of the implant itself (O'Sullivan et al, 2000) and thirdly, the loading conditions to which the implant is subjected (Friberg et al, 1991).

Loading conditions may differ due to a single or two-stage surgical placement technique (Sennerby L Roos J; 1998). In a two-stage technique, the implant fixture is placed, typically level with the crest of the bone and submerged beneath the soft tissue, for a healing period which may vary but has historically been recommended as three months in the mandible and six months in the maxilla. A two-stage protocol effectively eliminates any dynamic functional loads during this healing and osseointegration period. A single-stage technique is different in that the implant is exposed to the oral environment at the time of initial surgery and placement. In this case, a number of options exist in that the implant may be loaded (immediate loading) or may remain unloaded by the provision of a relieved prosthesis over the implant site for a healing period, which may typically vary from six to eight weeks.

#### *Loading protocols*

The alternative is early or immediate loading, in which a prosthesis or temporary restoration is placed directly at the time of surgery or a short period thereafter; perhaps a week. Immediate loading and delayed one-stage loading are very different. In delayed one-stage loading it is likely that the effectively unloaded implant is subjected to small dynamic loads, applied through the soft tissue and through intermittent contact with a prosthesis (Orenstein et al.; 1998). The clinical evidence for this protocol is that it is highly successful and that the dynamic loads if any are small enough and of appropriate frequency that they do not lead to a failure of osseointegration and

formation of a fibrous tissue capsule. However, there is no strong evidence to suggest that this early loading one-stage technique will actually accelerate bone formation or enhance the quality of bone formed.

Immediate and early loading, attachment of a prosthesis at the time of implant placement or shortly thereafter relies on the principal that the dynamic functional loading applied will be below the threshold which can induce failure of osseointegration and formation of a fibrous tissue capsule, and at a level whereby bone remodelling and formation may progress unhindered or even accelerated in the early healing stage. The ranges of clinical, anatomical and surgical parameters are very wide and therefore at present the selection, use and success of immediate and early-loading techniques are generally founded on the experience, knowledge and understanding of the clinician on an individual case by case basis.

*Primary Implant Stability*

It is clear that one of the keys to successful osseointegration is the primary stability of an implant. It is considered highly desirable that this level of stability should be as high as possible. In experienced hands it is commonly measured by the insertion torque necessary to place the implant. This is clearly a subjective feeling, but can give an experienced operator a level of confidence in the prospects of a successful outcome for a case.

Electronic drill controllers displaying graphs of insertion torque are available, but the interpretation of such data is difficult (Friberg B, Sennerby L, Roos J; 1995). An alternative technique is resonance frequency analysis (RFA)(Meredith N, Cawley P, Alleyne D; 1996), which has been available for some ten years. It utilises a non-destructive test method to measure the local interfacial stiffness of an implant and surrounding bone.

*Secondary Implant Stability*

It is evident in the first six to eight weeks following placement that there is more new bone formation in poorer quality bone, typically in the anterior maxilla. Here the blood supply can be good but there is an open trabecular network and primary stability is typically lower than in the mandible for example. In the mandible, there are smaller changes in stability and these may be accompanied by local remodelling rather than new bone formation (Meredith et al. 1997). This can result in a measurable increase

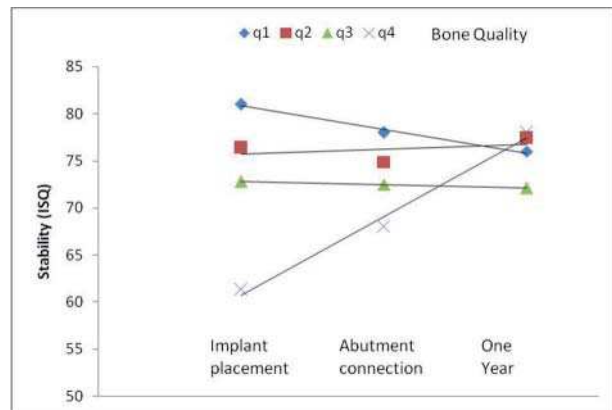


Figure 1. illustrates the changes in implant stability at different clinical stages following implant placement. (After Andersson et al. 2007)

in stability in bone qualities 3 and 4, more marked than in bone quality 1 and 2 (Andersson et al. 2007)

Clinical findings indicate that a large part of the healing and remodelling process, which is termed osseointegration, is probably completed within the first eight weeks of placement, under normal conditions. Higher primary stability at placement is also measured (Meredith N, Bok, K, Friberg, Sennerby ; 1997) in better quality and denser bone. O’Sullivan (2001) measured implant stability as a function of the changes in strain following implant placement for a period of two hours following placement. He observed a sharp initial fall in stability and decrease in interfacial strain.

This is interesting because it is not a biological or physiological phenomenon, what is occurring is mechanical stress relaxation in the bone following placement. This suggests that although a high level of stability and compression may occur at the time of insertion, this stability may decrease very rapidly thereby creating a higher risk situation. This could be especially important where implants are placed in poor bone quality, or where the bone has been artificially compressed to a high level by the use of osteotomes for example.

It is clear therefore that there is a very complex and subtle inter-relationship between bone quality, stability, geometry and placement technique.

*Implant Geometry*

A range of geometries has been available for dental implants for a number of years and their variation and relation to success do warrant some observations. It is interesting to note that historically the cylindrical implant has been associated with a relatively high

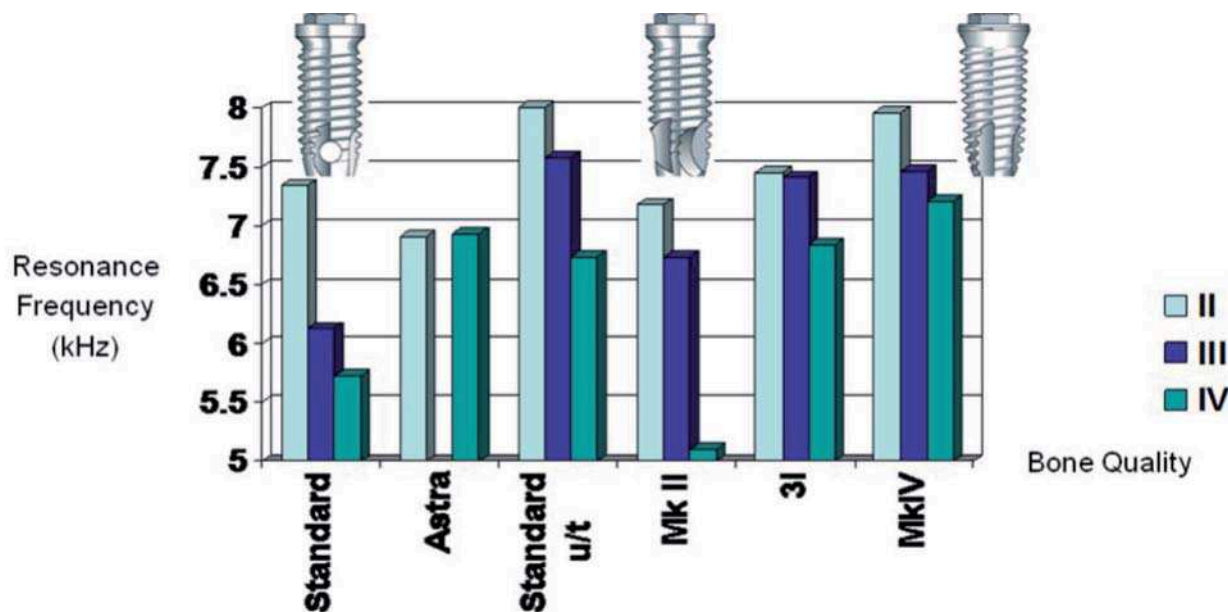


Figure 2. Implant stability for different implant types and bone quality in the maxilla (After O'Sullivan, Sennerby, Meredith; 2000)

incidence of implant failure (Albrektsson T, Sennerby L; 1991). This has also born some relationship to specific systems and it is important to be certain that the aetiology of this failure is due to the geometry alone; the evidence suggests that this geometry could play a part.

However, by relatively small modifications in geometry and placement technique it is possible to achieve a highly successful implant system, the Straumann (Basle, Switzerland) system was essentially cylindrical but with a small widely spaced thread super-imposed. The drilling protocol for this implant uses a small modification with the implant being 0.05mm larger than the preparation site. The idea is that this creates localised compression around the implant. In general, this seems to be successful, although the screw pattern used is that of a Thorpe screw, which was designed for use in orthopaedic surgery to pull bone plates together (Ansell R, Scales J; 1968).

Threaded implants with a close pitch and a deep profile (Brånemark; Nobelbiocare, Gothenburg, Sweden) are quite typical of another design of implant which has been clinically highly successful. The variations in stress distribution between different implant systems under applied loading would therefore appear to be quite substantial. However, both these geometry types (the threaded cylinder and the threaded implant) are equally successful clinically.

Implant geometries have not been routinely designed for use in specific bone or quality types. However, implants having a slightly tapered geometry (approximately 4° from parallel) have been introduced to create compression in poorer bone qualities and optimise stability (Brånemark MkIV; Nobelbiocare, Gothenburg, Sweden). Figure 2 Illustrates the stability at placement for a number of implant types in the human cadaver maxilla (O'Sullivan, Sennerby, Meredith; 2000)

*Static and dynamic stresses*

What is apparent is that two separate issues need to be considered in the successful placement and loading of a dental implant. These are the dynamic stresses experienced by an implant in function and the static stresses encountered during implant placement. Dynamic stresses and applied loads can be considerable once an implant has reached an equilibrium position in bone and healing has taken place.

Prior to this the nature, magnitude and direction of applied dynamic loads can influence the treatment outcome (Goodman et al. 1993). Static loads at the time of implant placement, however, are a consequence of those techniques or geometry that are designed to contribute to the maximal stability of an implant in bone. The use of slightly tapered threaded implants is one such way of seeking to increase stability in poor bone qualities (O'Sullivan 2001). Is compression and the application of high levels of primary stress a clinical issue? The answer is potentially yes, both at the time of placement in high initial bone qualities and at the time of abutment connection and

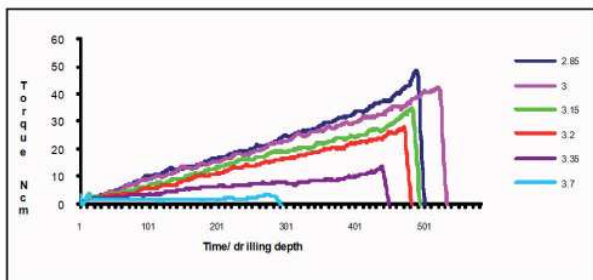


Figure 3. Variation in insertion torque with drilling depth as a function of time for 3.75mm implants placed in final osteotomy diameters 2.85-3.7mm. (O'Sullivan, 2001)

loading in two-stage implants (Misch C E,1990). A number of implant systems use a drilling sequence that creates a preparation site that is only very slightly smaller than the implant, being inserted. This will quite obviously create quite low levels of insertion stress. The evidence is that these implants are highly successful in average to good bone qualities where compression and stability are adequate and over-compression is avoided. In systems inducing a high level of compression, possibly by use of a tapered implant or a drilling sequence with a drill size much smaller than the implant diameter there are occasions when the consequences of over-compression may be early failure of the implant itself (Hobkirk JA, Rusiniak K,1977) (Ivanoff C-J 1999). Figure 3. illustrates the variation in insertion torque for 3.75 mm implants placed in final osteotomies of differing diameter. This clearly demonstrates a relationship between compression of the osteotomy site and insertion torque. (O'Sullivan, 2001)

Most implant designs do not directly address the optimisation of stability in poor bone qualities. Some implants have become available with a slightly tapered geometry, which creates local compression and thereby achieves good stability; these have been very successful.

The advantage of having a geometrical feature on the implant is that it does not rely on a complex placement or drilling protocol to create a level of compression, which may be variable in relation to its outcome. The slightly tapered implant thus provides a simple way of repeatedly and consistently offering an increase in stability in poor bone qualities (O'Sullivan et al. 2004b). The disadvantages of modified geometry implants of this type are that they can lead to over-compression when used in good bone qualities and they may either fail to seat or on some occasions may lead to failure. What is needed therefore is an implant geometry and a placement

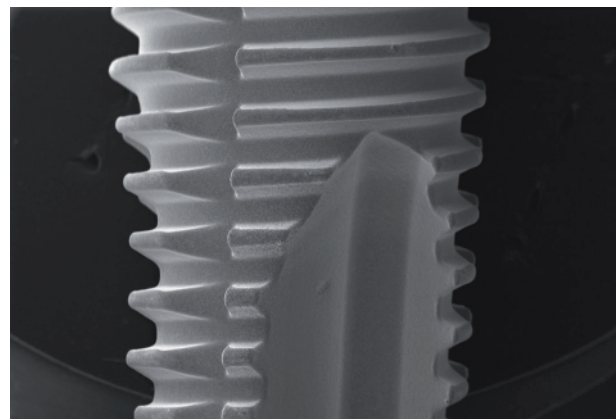


Figure 4. Bone relief chambers and cutting face

method which can achieve a high level of stability without over-compressing good bone and yet can optimise the compression and stability for placement in poor bone qualities. This would thereby optimise the success of implant placement in higher risk areas.

#### *Implant Design*

Such considerations have not been made hitherto in relation to implant design and placement techniques. This proposes a combination of geometry, surface characteristics and placement procedures which will optimise implant placement and stress distribution in all bone qualities. To achieve this it is evident that a tapered geometry will offer benefits in bone compression and there is good evidence that only a small degree of taper achieves a substantial increase in stability (O'Sullivan et al., 2004b).

It is therefore desirable to have an implant with a positive tolerance (taper) which will cause optimal compression in poor bone qualities. In order to address the seating, stability and compression levels within good bone qualities further consideration needs to be paid to the surface geometry. Many of today's implant systems use a thread-cutting geometry to tap a thread into the bone during insertion into a cylindrical hole. This works very effectively and creates a high level of bone-to-implant contact.

A possible thread refinement from current implants is altering the implant to bone volume ratio within the threads by reducing the thickness of the implant threads. An important feature of the geometry of the thread cutting face is that there is adequate volume in the relief chambers for bone clearance (Figure 4.). It is important that bone clearance chambers are designed to maximise the volume for

bone chip entrapment but also to provide maximal bone to implant contact on the threaded area. Historically some implant designs have been less successful because the bone collection chambers were very wide and very openly spaced (Friberg et al. 1997). It is also important that the cutting face of the self-tapping implant feature is sharp and without burrs. In order to optimise the placement of a threaded implant, having a positive tolerance in good bone qualities, a secondary cutting feature can be introduced along the side of the implant (Figure 4 and 5.). This secondary cutting face is much shallower than the apical cutting face and actually does not engage in soft bone qualities. In dense bone however, when the implant is inserted there will be elastic recovery during the insertion process such that the bone will engage the secondary cutting faces and a small amount will be removed.

Figure 6 illustrates an insertion torque profile for the Neoss implant demonstrating a near linear increase in insertion torque with a modulated plot attributable to secondary cutting (Luca et al., 2007). This will not impair the stability of the implant in the site but will create a different fits in dense bone quality or weak bone, thereby optimising stability in all bone qualities but without over compressing good bone. The combination of features relating implant geometry with forming and thread cutting in bone of different quality has been combined into a single implant design and the concept is called **TCF**<sup>®</sup> which represent a **T**hread **C**utting and a **T**hread **F**orming implant leading to cutting for optimal seating and forming for optimal stability.

Screw taps work differently from the use of progressively increasing drill sizes to match implant diameters. They are available for use on rare occasions where there is uniformly dense cortical bone along the whole implant length. In such cases, the compression occurring at the implant tissue interface is different from that under typical conditions where there is a combination of cortical and trabecular bone.

Under normal conditions the TCF feature of the Neo implant is designed to create an optimal level of compression, starting from the apex of the threads as the implant is inserted into a cylindrically prepared site. In uniformly dense bone, the use of a screw tap to pre-tap the site will create a level of compression on implant insertion that is uniformly applied to both the peaks and troughs of the thread, thereby achieving a comparable overall level of compression in a structurally



Figure 5. Implant design geometry for the Neoss implant

different quality of bone. Screw-taps are therefore recommended on occasions where bone density is extremely high and bone quality is very homogenous.

### *Insertion Torque*

Insertion torque is a commonly assessed qualitative parameter during implant placement. Placements and procedures vary considerably between systems and between operators. Some clinicians favour a very high level of final insertion torque and other operators work with a very gentle insertion technique, rarely encountering an insertion torque greater than 30Ncm.

Historically, a high final peak insertion torque may be variously affected by three phenomena. The implant may bottom out in the site, so that the final tightening torque is actually inducing very high levels of shear stresses at the implant tissue interface, as the implant butts against the bottom of the preparation site. A second cause of a high insertion torque may be contact at the flange of the implant with the crestal cortical plate, thereby achieving a high level of compression and static stresses. The third reason is a very high level of interfacial stresses leading to a high level of implant stability. On occasion, this may or may not accompany a level of over-compression and very rarely it may lead to implant failure.

The Neoss implant system has been designed to achieve the optimal level of compression and stability, for implant placements of bone in all qualities. This does not rely on a very high level of final insertion torque. Excellent results can be obtained using a gentle

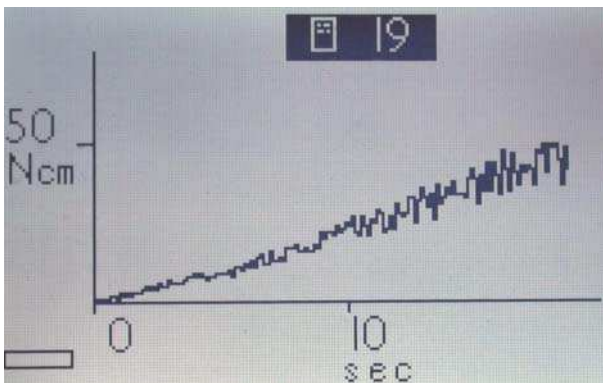


Figure 6. Insertion torque plot for Neoss implant.

technique where the insertion torque at any period during placement does not exceed 30Ncm. The optimal tissue response can be expected to be achieved if an insertion torque between 25 and 30Ncm is obtained.

Historically, if implants fail to seat or encounter very high insertion torques, surgeons typically remove the implant and use a screw-tap to aid the preparation. In the case of a Neo implant, if the insertion torque during placement reaches high levels then the implant can simply be anti-rotated a few turns and then re-inserted. This clears bone swarf from the cutting faces of the implant and reduces friction at the interface, thereby allowing smooth insertion without any risk of over-heating.

A second feature that is important during implant placement is the static stresses obtained between the interface of the implant flange and the crestal, cortical bone.

#### *Perifixtural bone loss*

A clear and well-recognised characteristic of the external hexed Brånemark implant is the loss of bone in the period following abutment connection and early loading from the level of the abutment-implant interface down to the first thread of the implant. The aetiology of this is not clear, but a number of hypotheses have been put forward. It has been proposed for example that there is micro-leakage between the abutment and the implant, of the implant abutment interface, resulting in the release of bacterial toxins causing a local peri-implant reaction and bone loss within a localised zone around this interface.

A second cause proposed is the surface characteristics of the implant; it has been suggested that one implant system with micro grooves has a more favourable coronal stress response and encourages bone

formation by the presence of these micro grooves.

A third, but not commonly discussed reason may well be related to mechanical stresses. This is particularly prevalent with the earlier designs of implants using commercially pure, type I titanium, which is relatively soft. In such cases the combination of a static load at implant placement around the flange between the implants and the cortical bone and then the superimposed dynamic stresses at the time of implant loading will cause a high level of mechanical stress and bending within the implant body, around the neck, between the flange and the threaded body of the implant. The bone response to these localised stresses is likely to be resorption; the high levels of stress at the implant neck can be visualised by a stress profile, superimposed on an implant in bone in this region.

It is therefore highly desirable to have a flange and neck design that minimises both the static stresses at placement and the dynamic stresses on the functional loading. The Neoss implant has been designed specifically without a neck region, as in the external hex implant designs, and the thread leads directly into the flange. The relationship between the flange and the threaded portion of the implant is slightly different for the 3.5, 4 and 4.5mm diameters. This enables the use of one common abutment connection without impairing the fit of seating of the implant in the surrounding bone.

In the flange region, it is therefore possible to assess the level of compression occurring in the flange during implant insertion. The Neo system has great For a two-stage implant with a high level of surrounding bone a counter sink can be used to provide the optimal seating, minimising static stresses and optimising the interface between the flange and the surrounding bone, thereby providing optimal conditions for direct bone formation. The Neo implant system is therefore designed with a number of features in geometry, preparation technique and material properties that jointly result in the optimal biomechanical relationship between a dental implant and the surrounding bone.

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